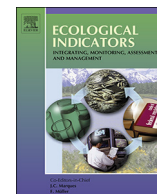




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## Ecological Indicators

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## Original Articles

## Evaluation of indicators for agricultural vulnerability to climate change: The case of Swedish agriculture

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## ABSTRACT

Agriculture is often described as one of the sectors most vulnerable to future climate change, and its vulnerability is commonly assessed through quantitative indices. However, such indices differ significantly depending on their selected indicators, weighting mechanisms, and summarizing methods, often leading to divergent assessments of vulnerability for the same geographic area. The use of generic indicators might also lead to a loss of information about contextual risks and vulnerabilities. This may reduce the perceived usefulness of indices among stakeholders.

This study analyses the role of indicators in assessing agricultural vulnerability to climate change. It analyses how indices are understood and used through three separate focus group sessions, involving agricultural experts professionally active in south-eastern Sweden. The paper presents how agricultural practitioners perceive a set of common vulnerability indicators, presented through a visualization tool, and their relevance, logic, and applicability to assess and address vulnerability to climate change. The results of this study contribute with perspectives on (i) the relevance and applicability of the commonly used generic indicators for agricultural vulnerability (ii) the assumed correlation of indicators with climate vulnerability and (iii) the identification of missing vulnerability indicators. The study finds that commonly used vulnerability indicators are perceived hard to apply in practice, as definitions and thresholds are often depending on the geographical and temporal scale, as well as the regional context. Additional exposure factors that were identified included extreme events, such as heavy precipitation and external factors such as global food demand and trade-patterns. Further, participants expressed that it is important to include indices that combine effects of multiple climatic changes and in-direct factors, such as policies, regulations and measures. Inherent complexities, context dependencies, and multiple factors should further be included, but entail difficulties in developing suitable indicators. These factors must be addressed by a broader set of qualitative and quantitative indicators, and greater flexibility in the assessment methodology. The interactive vulnerability assessments presented in this paper indicate a need for an integration of quantitative and qualitative aspects and how such indicators could be developed and applied.

## 1. Introduction

Agriculture is one of the sectors most vulnerable to future climate change and has as such been the object of multiple studies in recent years (Smith et al., 2014). In attempting to outline and compare the agricultural vulnerability of different world regions, various quantitative assessments of climate change vulnerability have been conducted, generating composite indices based on sets of indicators (cf. Dong et al., 2015). Such indicators usually span multiple dimensions of the vulnerability concept, capturing the exposure, sensitivity, and adaptive capacity of a system (Wiréhn et al., 2017). Although assessing vulnerability across large geographical areas and systems, composite indices

have been criticized because they are arguably insensitive to contextual differences and to the spatial and temporal distributions of impacts, producing oversimplified assessments (Saisana and Tarantola, 2002; Hinkel, 2011). When comparing the performance of composite indices covering the same geographic area, Wiréhn et al. (2015) found that the results differed significantly due to the selection, weighting, and summarizing of selected indicators. A critical starting point for developing quantitative vulnerability assessment methods is selecting representative indicators that are sufficiently comprehensive to be applicable in different geographic locations, while sufficiently sensitive to different impacts, crops, and production methods (Dong et al., 2015).

This study analyses the role of indicators in assessing agricultural

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vulnerability to climate change. Specifically, we study how indicators can be approached when assessing vulnerability of Swedish agriculture. As empirical base, visualization-supported focus group interviews were held with practitioners with vast experience of Swedish agriculture to explore how they relate to and apply existing vulnerability indicators for Nordic agriculture, weight indicators and discuss opportunities and constraints when applying indicators. Based on this analysis, we discuss how vulnerability indicators can be further developed to address the challenges identified. As most indicator-based vulnerability studies have so far targeted regions that are considered as more exposed to climate change, this study contributes to the literature by focusing on the function of indicators in regions generally perceived as less exposed to the worst effects of climate change. In a global context, the Nordic region and particularly its agricultural production may be considered resilient to or even a winner from climate change (O'Brien et al., 2004; Bindi and Olesen, 2011). But the question whether a system ought to be considered vulnerable depends on the scale of analysis and the context of the assessment (O'Brien et al., 2004). In its latest assessment report (Kovats et al., 2014), the Intergovernmental Panel on Climate Change (IPCC) has for the first time emphasized the diverse impacts and possible challenges facing northern European agriculture. For the Nordic region, scientific literature on agricultural vulnerability to climate change has focused predominantly on physical impacts on crop production (Wiréhn, 2018), while few studies have considered sensitivity and adaptive capacity (e.g. Kvalvik et al., 2011).

This study builds on the conceptual framework for interactive quantitative vulnerability assessments presented by Wiréhn et al. (2017). This framework addresses the limitations of vulnerability assessments, outlining the need for: i) clarity regarding the applied definition and conceptualization of vulnerability, ii) transparency regarding the applied quantitative vulnerability assessment method, and iii) reflexivity in conveying results and mapping vulnerability. This study strives to link quantitative and qualitative perspectives to provide insights into the overall climate vulnerability of Swedish agriculture. Experimental focus group sessions were held with agricultural experts professionally active in Sweden, using the AgroExplore vulnerability assessment tool (Wiréhn et al., 2017) to build an understanding of how experts perceive the factors affecting agricultural vulnerability and, furthermore, of how indicators for these factors can be defined to better capture the complexity of vulnerability in the region.

## 2. Background

### 2.1. Climate change impacts and vulnerability

Recent scientific studies outline that climate change will bring both opportunities and challenges to Nordic agriculture (Kovats et al., 2014). The future climate is projected to be wetter in the Nordic region, except in Denmark and southern Sweden in summer (Strandberg et al., 2014). Temperatures are generally projected to increase, with the highest increase experienced during winter in the north-eastern regions. This temperature increase is expected to result in an extended growing season, particularly due to the earlier onset of spring (Strandberg et al., 2014). This extended growing season and associated expansion of climatically suitable agricultural land is described as the key reason for increased production potential in northern Europe (Fischer et al., 2002; Olesen and Bindi, 2002; Kovats et al., 2014). However, a recent literature review found that scientific studies of the possible impacts of climatic change on agricultural production diverge in their findings, setting the course of adaptation in an uncertain direction (Wiréhn, 2018). Agricultural challenges in a changing climate outlined in recent studies include: increased risk of pest and weed infestations (Marttila et al., 2005; Fogelfors et al., 2009; Wivstad, 2010; Uleberg et al., 2014); accelerated phenological development (Maracchi et al., 2005; Kristensen et al., 2010; Peltonen-Sainio et al., 2010); complicated conditions for spring tilling (Fogelfors et al., 2009), for sowing (Hakala

et al., 2012; Uleberg et al., 2014), and for harvesting (Jordbruksverket, 2013); as well as increased risks of erosion, nutrient leaching (Marttila et al., 2005; Eckersten et al., 2007; Jeppesen et al., 2010), and yield losses due to increased climate variability (Rötter et al., 2012).

Though the scientific literature on adaptation in Nordic agriculture is growing, it is still limited to a few perspectives and identifies several trade-offs between various adaptation policies and measures that serve different purposes (Wiréhn, 2018). Consequently, to properly assess agricultural vulnerability to climate change and identify essential adaptation measures, there is a particular need to enhance our knowledge of biophysical and socio-economic factors that decrease sensitivity or increase adaptive capacity in Nordic agriculture.

### 2.2. Vulnerability assessment methodologies

Critical to creating a robust agricultural production system is understanding the system's vulnerability to climate change and the corresponding underlying factors. Vulnerability to climate change or natural hazards is commonly assessed in several sectors, including agriculture (O'Brien et al., 2004; Berry et al., 2006; Dong et al., 2015). Scholarly traditions in human–environmental systems have resulted in a range of conceptualizations and methods for assessing vulnerability (Füssel, 2007). Interdisciplinary research usually advocates integrated vulnerability assessments that address both biophysical and socio-economic dimensions (Eakin and Luers, 2006; Füssel and Klein, 2006; Füssel, 2007). Generally, different categories of vulnerability assessments can be distinguished based on the intended goal with the assessment, such as, regional comparison; general assessment of future stressors; and enhancing the understanding of the factors that determine vulnerability, which may serve as a foundation for designing adaptation strategies to reduce vulnerability (Adger et al., 2004; Eriksen and Kelly, 2007). One of the most common ways to quantitatively assess climate vulnerability is to use indicators. Indicator-based methods are suitable in vulnerability assessments since vulnerability is a theoretical phenomenon that cannot be measured like observable phenomena (Hinkel, 2011). Indicators are used to make theoretical concepts operational (Birkmann, 2006; Hinkel, 2011; Becker et al., 2015) through variables that serve as operational representations of characteristics, qualities or properties of a system (Gallopin, 1996).

The procedure of indicator-based assessments typically involves defining the goal, the context and the conceptual framework of the study; selection of indicators; data collection and management; aggregation of indicators (if useful and required); and presentation of results (Birkmann, 2006; Binder et al., 2010; Asare-Kyei et al., 2015; Becker et al., 2015). When conceptualizing vulnerability as a function of exposure, sensitivity, and adaptive capacity, indicators are used to represent these key aspects that jointly define the vulnerability of the studied system (Adger et al., 2004). These three aspects are often combined into a composite index (Nardo et al., 2008). Hence, composite indices are suitable for vulnerability assessments because of their ability to capture the multiple dimensions of vulnerability (Nardo et al., 2008). Furthermore, the indices are commonly used to map vulnerability in geographic visual representations (Preston et al., 2011).

Although the use of indicators is feasible for vulnerability assessments, the approach involves considerable pitfalls and has received significant criticism (Birkmann, 2007; Eriksen and Kelly, 2007; Vincent, 2007; Hinkel, 2011). Birkmann (2007), for example, points towards shortcomings regarding up and down scaling of indicators, related to challenges of contextualizing indicators and indicator approaches to various contexts and scales. Other challenges and uncertainties are related to the selection of indicators (Vincent, 2007; Binder et al., 2010); uncertainty in validity robustness of indicators and conceptual frameworks (Eriksen and Kelly, 2007; Vincent, 2007; Becker et al., 2015); data accuracy and accessibility (e.g. Becker et al., 2015); uncertainty in indicators' assumed relationship with vulnerability (e.g. Vincent, 2007); the lacking coverage of vulnerability dynamics (Luers et al.,

2003; Eriksen and Kelly, 2007; Vincent, 2007); aggregation and weighting of indicators (Eriksen and Kelly, 2007; Barnett et al., 2008); and lacking transparency in the methodology and assumptions (Eriksen and Kelly, 2007; Becker et al., 2015). Moreover, while vulnerability assessment methods vary (Soares et al., 2012), so do their results (Jones and Andrey, 2007; Wiréhn et al., 2015). Among the drawbacks of vulnerability indicators and composite indices are the arbitrary choices of methods. Wiréhn et al. (2015) demonstrated that the choice of methods for weighing and summarizing indicators significantly determines the score of a composite index.

Yet, despite challenges with indicator-based methods, they provide valuable tools for systematic evaluation and discussion, i.e. what causes vulnerability and how can it be reduced (Birkmann, 2007). Interactive vulnerability mapping is one way to address the challenge of creating vulnerability indices. With interactive vulnerability mapping, the user can, for example, select, categorize and weight relevant indicators of vulnerability, enabling exploration of the indicators and how they are applied and represent vulnerability in an assessment (Wiréhn et al., 2017). Such interactive mapping may therefore function as an informative analytical method for assessing vulnerability (Neuvonen et al., 2015), and can thus open up the “black box” of composite indices.

### 3. Material and methods

#### 3.1. Study design

This study applies a visualization-supported focus group methodology (Wibeck et al., 2013; Neset and Wibeck, forthcoming). This methodology expands the traditional focus group setup of four to eight participants by engaging them in a facilitated discussion using visual tools as a point of departure. Such tools can range from a set of images to highly interactive visual interfaces. AgroExplore (Wiréhn et al., 2017), used as the methodological basis of this study, is an interactive tool designed specifically to support expert discussion of agricultural vulnerability as well as explorative dialogue regarding specific indicators, their thresholds, and relevance to Nordic agriculture. Since this study focuses on the general understanding of climate vulnerability and the evaluation of data content, vulnerability indicators, weighting mechanisms, and inherent thresholds, it does not include an assessment of the aspects of geographic visualization, such as a usability evaluation of tool design and functionality per se (Andrienko et al., 2002; Coltekin et al., 2009).

#### 3.2. Vulnerability assessment in AgroExplore

AgroExplore has been designed as a research tool to address the lack of transparency in vulnerability assessment studies. As discussed in Section 2.2, vulnerability indices can differ strongly from one another depending on the selected indicators, weighting mechanisms, and summarizing methods (Adger et al., 2004; Jones and Andrey, 2007; Wiréhn et al., 2015). AgroExplore has been designed to increase transparency through supporting interactive vulnerability mappings presented in a visual interface. Users can select and explore vulnerability indicators, set indicator weights, as well as move indicators between three vulnerability dimensions: exposure, sensitivity, and adaptive capacity. Vulnerability indicators are presented with their units and thresholds, facilitating expert discussions of their relevance and possibly needed changes. The assumed correlation of each indicator with the vulnerability dimension, i.e. whether it is assumed to increase or decrease exposure, sensitivity or adaptive capacity, is also given. The vulnerability indicators integrated in the current version of AgroExplore are presented below (Table 1). These indicators have been selected based on previous agricultural indices as well as relevant literature (Wiréhn et al., 2015).

The AgroExplore tool builds transparency in interactive mapping by

enabling users to follow the steps leading to the final vulnerability representation. As a result, the mapped composite index can be treated as a summary of all dimensions and choices leading to a certain representation. Elements of information visualization are implemented to increase the effectiveness of the interactive mapping, including an interactive map display embedded within a visual interface enriched with other map or data displays, showing either auxiliary characteristics or the same information but in a different way. Such a complex approach, broadly known as geographic visualization, or more precisely, co-ordinated and multiple views (Roberts, 2008), has been employed in various contexts (Grainger et al., 2016), and has proved suitable for acquainting users with sophisticated concepts (Bohman et al., 2015).

Geographic visualization, facilitates an interactive vulnerability assessment approach (Wiréhn et al., 2017) in which a personalized selection of vulnerability indicators can be interactively classified into sub-indices. The resulting map is intended to facilitate knowledge acquisition as well as collaborative learning between researchers and stakeholders. Prior studies have pointed out the advantage of collaborative learning executed through interactive vulnerability assessment for integrating quantitative and qualitative approaches, which can lead to more informed assessments, compared to studies that rely on solely quantitative methods or in which only one actor type – either experts or practitioners – is involved in the assessment validation (Rød et al., 2015). Validation through collaboration between various stakeholders by using a geovisualization tool can further provide valuable results regarding the underlying factors of agricultural vulnerability to climate change, and how these are understood by stakeholders.

The AgroExplore interface consists of five sections: four choropleth map displays and a data display (Fig. 1). There are three choropleth map displays in the upper part of the interface: an exposure map, a sensitivity map, and an adaptive capacity map (left to right). The users can move vulnerability indicators across these three map displays in order to compose three vulnerability sub-indices in accordance with their preferences. They can also use horizontal sliders to set the indicator weights (from 0 to 5). The fourth map display showing the geographical distribution of the agricultural vulnerability is located in the lower-left part of the interface. It enables the users to set the weights of the three sub-indices (i.e. exposure, sensitivity, and adaptive capacity) and view the final vulnerability scores. The lower-right part of the interface is in turn used as a data display. Here the users can enable one of three views: a Sankey diagram, a parallel coordinate plot, or a datagrid (the last two are not shown in Fig. 1). This display also enabled the focus group participants to compare their final settings.

#### 3.3. Study setup, participants, and data collected

The focus group sessions were held in the Norrköping Decision Arena, an immersive research environment in which up to ten participants can engage in interactive sessions. The arena provides a flexible environment for displaying multiple screens simultaneously, as participants can connect their mobile units to appear on the 360° screen. Such settings enable immediate responses to data such as images, maps, or graphics presented during a session. In this particular focus group setup, participants and facilitators were seated at a round table and provided with a laptop featuring the AgroExplore tool. The tool was directly displayed on the 360° screen. As such, participants could, when discussing their own AgroExplore exploration and results, present and compare their screens without any interruption.

The empirical data in this study were collected during three focus group sessions in June 2015, each involving 3–5 experts in the field of agriculture, professionally active in the county of Östergötland in south-eastern Sweden. Participants were representatives of the Swedish Board of Agriculture, the county board, branch organizations, and private consultancies. Some of the participants were also part-time farmers and referred during the focus group sessions to their farming experience in addition to their professional knowledge. With such diverse

**Table 1**

Indicators together with their definitions and abbreviations categorized by the vulnerability dimensions Exposure, Sensitivity, and Adaptive Capacity of Nordic Agriculture, as presented in AgroExplore. A more detailed description of the data sources is provided in Wiréhn et al. (2015).

Vulnerability dimension	Indicator	Definition of indicating variable	Abbreviation
Exposure	Spring temperature change	Spring <sup>a</sup> temperature change <sup>b</sup>	SpringTemp
	Summer temperature change	Spring <sup>c</sup> temperature change <sup>b</sup>	SumTemp
	Winter temperature change	Winter <sup>d</sup> temperature change <sup>b</sup>	WintTemp
	Annual precipitation change	Annual precipitation change <sup>b</sup>	AnnPrec
	Spring precipitation change	Spring <sup>a</sup> precipitation change <sup>b</sup>	SpringPrec
	Autumn precipitation change	Autumn <sup>e</sup> precipitation change <sup>b</sup>	AutPrec
	Growing season change	Change <sup>b</sup> in days per year with average temp > 5 °C	GrowSeason
	Change in spring frost days	Change <sup>b</sup> in days with min temp below 0 °C and max temp above 0 °C in spring <sup>c</sup>	SpringFrost
	Change in autumn frost days	Change <sup>b</sup> in days with min temp below 0 °C and max temp above 0 °C in autumn <sup>e</sup>	AutFrost
Sensitivity	Crop yield	Mean crop yield (kg/ha)	CropYield
	Arable land	Arable land/total land area	ArableLand
	Employment in agriculture	Number employed in agriculture, part-time and permanent, divided by total working population (%)	AgriEmployment
	Population density	Population per km <sup>2</sup>	PopDensity
	Irrigated land	Area that can be irrigated divided by the arable land (%)	IrrigLand
	pH	pH – H <sub>2</sub> O in the topsoil	pH
	Soil organic matter	Soil organic matter in the topsoil (%)	SOM
	Erosion risk	Modelled erosion risk (t/ha/yr)	ErosionRisk
	Phosphorus content	Ammonium lactate-acetate soluble phosphorus ( <i>P</i> -AL) in the topsoil	PhosphorusCont
	Crop diversity	Sum of (percent of area sown with <i>x</i> crops/number of <i>x</i> crops) (Bhatia, 1965)	CropDiversity
Adaptive capacity	Clay content	Clay content of topsoil (%)	ClayCont
	Small farm holdings	Number of farms with holding size less than 2 ha relative to all farms (%)	SmallHoldings
	Farm income	Farmers' income (SEK/household)	FarmIncome
	Fertilizer consumed	Standardized sum of phosphorus (P), potassium (K), and nitrogen (N) from added manure and fertilizer (kg/ha)	Fertilizer
	Unemployment rate	Unemployed people seeking a job, percentage of total population	UnemploymentRate
	Social welfare payments	Economic assistance (SEK/capita)	SocialWelfare

<sup>a</sup> Spring = March–May.

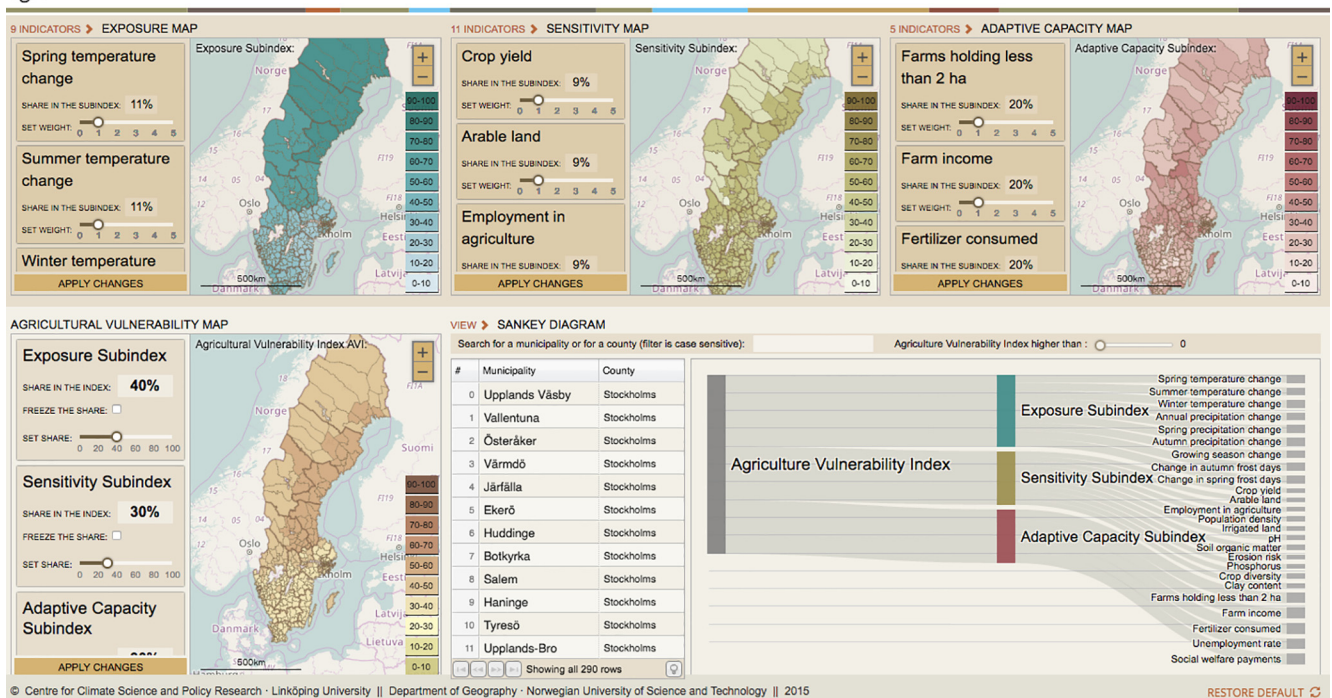
<sup>b</sup> All climate change variables include the change in the parameter over the 2021–2050 period compared with 1961–2000 from the ensemble mean of six GCM scenarios for emission scenario RCP 8.5 downscaled with the Rossby Centre's regional model, RCA4.

<sup>c</sup> Summer = June–August.

<sup>d</sup> Winter = December–February.

<sup>e</sup> Autumn = September–November.

## agroEXPLORE



**Fig. 1.** The interface of the AgroExplore tool used as framework to conduct interactive vulnerability assessments with agricultural stakeholders in Sweden (June 2015).

backgrounds, the participants attending the sessions, although consistent regarding the domain, constituted a group of users with diverse skills, experiences, expertise, and duties. In the focus group sessions, participants discussed factors that, from their perspective, influence agricultural vulnerability. Thereafter, the experts specifically assessed a set of common vulnerability indicators – presented in AgroExplore – analysed according to relevance, logic, and applicability. A particular restriction was the fact that all information was in English, since the terminology had not yet been translated into Swedish. This was solved by oral translations, but was observed to impede the exploration of indicators and settings to some degree.

The collected empirical material contained both qualitative and quantitative data. The qualitative material included transcripts of the three audio-recorded focus group sessions, which lasted approximately two hours each. A brainstorming exercise was conducted at the start of each session. This exercise was designed to identify any issues or factors that affect agricultural vulnerability by allowing individual participants to add concepts (i.e. words or sentences) using a web-based tool. When all participants had added their concepts, these were saved and gathered on a “moderator screen” to support common discussion of these factors and of the extent to which they were covered in AgroExplore. Furthermore, quantitative material was collected in the form of the final individual AgroExplore settings, which each participant saved after having completed a full agricultural vulnerability analysis.

The transcripts of the audio-recorded focus group sessions were analysed using thematic analysis (Kvale and Brinkmann, 2009), supported by data collected during the brainstorming exercise as well as the individual AgroExplore setting results. Thematic areas were inductively derived from the data material and are presented in the three sub-sections of the Section 4.

## 4. Results

The analysis of the qualitative data (i.e. transcribed dialogues) revealed rich discussions and evaluations of vulnerability indicators included in the AgroExplore tool, but also wider-ranging discussions following the brainstorming exercise regarding the vulnerability of agriculture and other aspects that might not be captured by the presented indicators. The thematic areas derived from the analysis were: (1) the selection and relevance of specific indicators and their thresholds; (2) the correlation of single indicators with the climate vulnerability dimension; and (3) identification of missing vulnerability indicators.

### 4.1. Assessment of vulnerability indicators and their thresholds

The discussion of indicators varied between the focus groups in terms of which vulnerability dimension received the main focus. Nevertheless, all participants engaged in the discussion of indicators of exposure, sensitivity, or adaptive capacity. Participants deselected or set the indicators' weight to zero for several indicators. Only three indicators, namely, *spring* and *autumn precipitation change*, as exposure indicators, and *farm income*, as an indicator of adaptive capacity, were selected by all participants (the indicators and information on their selection and average weights are presented in Fig. 2). The discussion revealed that participants decided to deselect an indicator not primarily because they considered it irrelevant, but rather since they perceived themselves to have too little knowledge of how a particular indicator influences a specific vulnerability dimension.

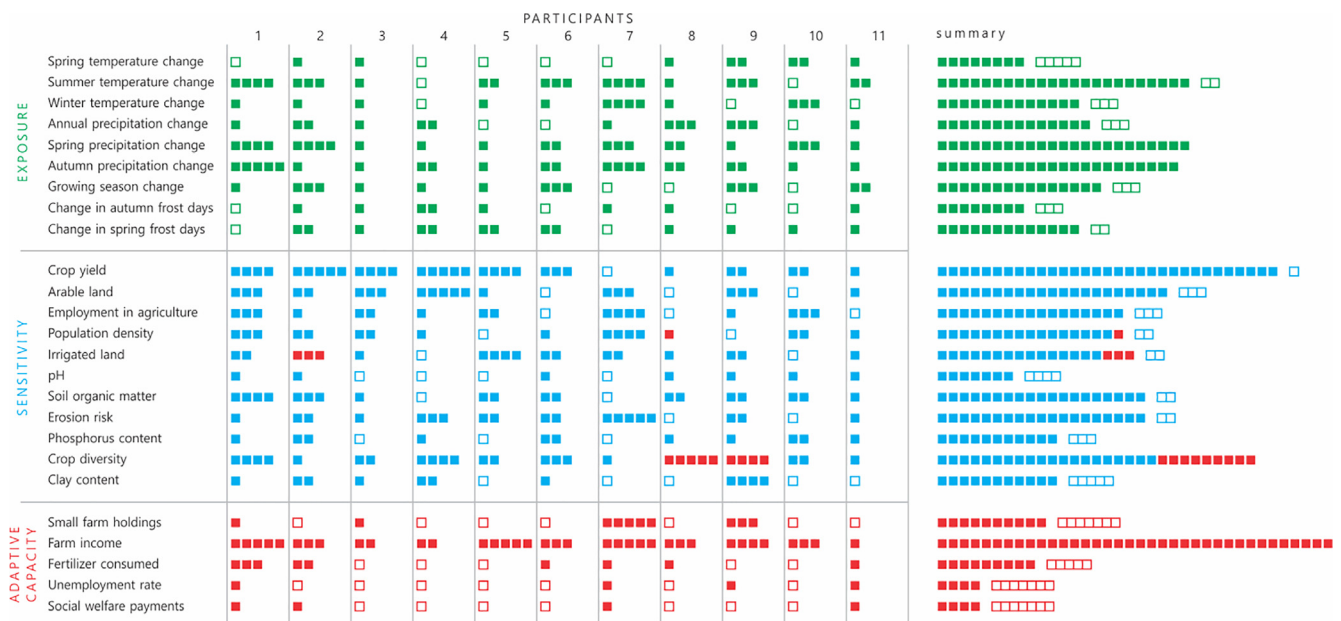
Exposure indicators, which are exclusively climatic change indicators in the present version of AgroExplore, were most intensively discussed in relation to three issues. First, the question was raised as to whether a single climatic factor in itself increases or decreases exposure or whether this is more an issue of combinations of two factors (e.g. temperature and precipitation). Second, climatic change was overall considered more important in terms of extremes rather than average

values, which is the case in the current version of AgroExplore. This referred in particular to increased precipitation, in which the timing and intensity of rainfall were claimed to be crucial to whether increased rainfall was considered to have a positive or negative effect. Third, several of the climatic exposure indicators were weighted differently depending on the crop type that the participants considered in their responses. An additional issue that was discussed in all groups concerned the positive or negative correlation of climate indicators with the overall vulnerability.

In the current version of AgroExplore, the climate exposure indicators are the seasonal average temperature and precipitation. Indicators of spring and summer temperature and precipitation were generally considered more important than indicators of climatic change in autumn, and *spring* and *autumn precipitation change* were the overall highest-weighted exposure indicators (see Fig. 2). Winter temperature was discussed in relation to frost in the ground, winter rest, and the survival of pests and weeds. As such, the indicator *change in frost days* in spring and autumn were agreed to have a strong impact on agriculture, although they did not receive high weighting from any of the participants during the discussions. The overall higher temperatures were frequently considered to decrease the level of exposure, leading to longer growing seasons. The indicator *growing season change* was generally discussed as an important factor but not weighted particularly high in the vulnerability indices. Three participants excluded this indicator as an exposure indicator, with the frequently expressed reasoning that the exposure dimension refers exclusively to negative impacts. Some parts of the focus group discussion considered the impact of extreme precipitation, which could “destroy all your planning” (authors' translation). In particular, the indicator *annual precipitation change* was considered irrelevant by most participants, and only to some extent were the indicating variables of seasonal change considered to offer sufficient resolution for assessing the vulnerability of the agricultural sector. Several participants argued that the impact of temperature was not relevant in all seasons, but the temperature changes in spring, summer, and winter were nevertheless intensively discussed.

In several of the focus group discussions, participants frequently reiterated that climate impacts were dependent on specific circumstances of the system in which they occur. While all participants were based in the county of Östergötland, they were considering climate changes relative to current challenges experienced in other Swedish regions (e.g. droughts in southernmost counties) or to particularly vulnerable crops. Similarly, participants argued that indicators of climate change (e.g. changes in precipitation) could have either a positive or negative correlation with vulnerability depending on the region and type of agriculture considered (cf. Section 4.3).

Sensitivity indicators included in AgroExplore cover various issues and refer to current agricultural practices, infrastructure, and physical (i.e. soil) or socio-economic conditions. Factors that indicate physical soil conditions, specifically *soil organic matter*, *clay content*, and *phosphorus content*, were regarded differently by the participants. Most participants agreed that *soil organic matter* was important for low sensitivity. As one participant explained, “If your soil is in good physical shape, it makes you less vulnerable if the climate changes and acts weird” (authors' translation). Nevertheless, several participants said that the relevance of the soil *clay content*, *phosphorus content*, and *pH* indicators was unclear, particularly since these indicators were presented at a municipally aggregated level. This was also evident in the weightings of these indicators, with almost half of the groups deselecting *clay content* and about a third deselecting *phosphorus content* and *pH*. *Clay content* was mainly considered relative to clay's ability to retain water during longer dry periods. Similarly, the indicator *erosion risk* was deselected by two participants because they considered it unimportant, while other participants considered it highly relevant, arguing that “areas that have soil with high erosion risk might have problems in the future” (authors' translation). *Crop yield* was generally considered relevant as a sensitivity indicator and was also the highest-weighted



**Fig. 2.** Participant weightings of the Exposure (green), Sensitivity (blue), and Adaptive Capacity (red) indicators presented in AgroExplore (2015). Each column represents a participant. Each filled square represents the selected weighting for an indicator, whereas blank squares represent a deselected indicator. The summary shows the overall weighting for each indicator (filled squares) and a summary of how many participants that deselected each indicator (blank squares). The red squares in the Sensitivity section show indicators that have been ‘moved’ by the participant from sensitivity to adaptive capacity. For indicator descriptions, see Table 1. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

sensitivity indicator (see Fig. 2). Likewise, *crop diversity*, described as a way to “spread the risk” as well as a “reflection of mental adaptability”, was also weighted high. In the latter case, two participants thought of it as an indicator of adaptive capacity rather than sensitivity.

The indicator *arable land* was considered from two perspectives by the participants. While a high share of arable land could mean that “if you have a lot, you’ll lose a lot”, it might also imply that “if you have large areas, the risk is dispersed” (authors’ translation). Another argument was that the share of agricultural land would not increase the sensitivity of the municipality, since other land uses (e.g. forestry) can also be sensitive to climate change, although in different ways. The diversity of views regarding share of arable land as a sensitivity indicator was evident in the participants’ settings, which ranged from deselecting it to assigning it a medium weighting; one participant even gave it the highest weighting.

Socio-economic indicators were perceived as harder to assess. Several participants discussed indicators such as *population density* and *employment in agriculture* as possibly being more relevant as factors influencing the adaptive capacity of a region. However, only one participant changed the settings so that these indicators were part of adaptive capacity, while three participants deselected them altogether. *Population density* was also considered an indicator of potential conflicts of interest regarding natural resources; as one participant put it, “if there’s a conflict between different water resources, for example, irrigation versus drinking water, then it could become a problem” (authors’ translation).

While one participant moved the indicator *irrigated land* to the adaptive capacity section, since it was interpreted as enabling adaptation to future droughts, others argued that “having the infrastructure or not” was relevant to the overall sensitivity of a region, and could decrease vulnerability. In addition, two participants deselected the indicator. Their reasons for doing so, however, were not specified in the discussions.

Related to adaptive capacity, several indicators listed under the adaptive capacity section by default or moved there by participants were debated intensively concerning their relevance and correlation with overall vulnerability. The indicator *small farm holdings* was

particularly debated, but mostly in relation to the threshold: all participants agreed that it was set too low at 2 ha. The debate on thresholds was not settled conclusively in any of the focus groups, however, a threshold of at least 50 ha was suggested by some participants, who considered the 2 ha threshold just a “large garden”. The discussion of smaller versus larger farm holdings touched on the critical question of whether a smaller farm indicates a higher adaptive capacity, since the enterprise would likely be supported by outside incomes. In that case, the critical factor would be the types of incomes on which the farmer is dependent, rather than the farm size. On the other hand, another argument was that larger farms would have a higher investment capacity and hence ability to adapt more easily to climate impacts or changing conditions. In the end, only four participants chose to include *small farm holdings* as an adaptive capacity indicator.

*Farm income* was another debated indicator, not as much in terms of thresholds, but mostly regarding the distinction between “profitability” and “income”. Profitability was regarded as more important than income as a factor determining adaptive capacity, but *farm income* could be used as a proxy indicator of profitability. Participants tended to agree that farms with greater financial margins have higher adaptive capacity, since they would have the ability to make the investments required both to cope with sudden impacts and for long-term adaptation. *Farm income* was therefore the only adaptive capacity indicator that all participants included and, moreover, it was weighted markedly higher than were any of the other adaptive capacity indicators. Some participants considered *fertilizer consumed* to be irrelevant, having “nothing to do with adaptive capacity”, and about half of the group deselected it, while others agreed that it was somewhat relevant. However, the participants who did include the indicator weighted it low and did not consider it as important as other factors.

#### 4.2. Positive or negative correlation of indicators with vulnerability

The focus group discussions frequently concerned the correlation between different indicators and vulnerability. As described above, correlations were predefined in AgroExplore and could not be manipulated interactively by the user. However, for each of the

vulnerability indicators, the positive or negative correlation is specified when selecting the “indicator overview” (see Table 1).

Just as the exposure indicators generated intense discussions of specific definitions and thresholds, the correlation with vulnerability was equally subject to different interpretations in several instances. Participants frequently argued that the positive or negative correlation of a climatic change depended on the specific crops and/or circumstances of the discussed agricultural region. An increased winter temperature, for example, could be considered as both increasing and decreasing vulnerability, depending on the context. It would increase vulnerability by decreasing ground frost and winter rest, which were mentioned as important aspects of the annual cycle, whereas it would decrease vulnerability by possibly increasing the length of the growing season. Furthermore, the timing of climatic events was important for the correlation with vulnerability. In particular, the timing of precipitation combined with its intensity is crucial, and any sudden events are more likely to increase vulnerability. In that sense, discussions of whether increased temperature (particularly in summer) and summer precipitation would be negatively or positively correlated with vulnerability resulted in the notion that there was a narrow margin of error in determining what magnitude of increase might positively affect agricultural productivity when particular events (in particular, rainfall) occur.

Of the indicators of sensitivity and adaptive capacity, the participants discussed several examples in which the positive or negative correlation of the indicator depended on the perspective taken. The indicator *arable land* was one such example, in which an increased share of arable land could be interpreted as increasing vulnerability, while also being a possible indicator of a negative correlation, as more arable land might disperse the risk of a negative impact. Similarly, the effect of the indicator *clay content* also depended on the perspective: while it is a factor negatively correlated with vulnerability in terms of keeping moisture in the soil, it also affects production in terms of the required frost in the ground during winter.

Socio-economic indicators were frequently discussed based on different interpretations in terms of negative or positive correlations. While *population density* was set to have a positive correlation with vulnerability, several participants agreed that it should be set as negative, arguing that a high population density would imply “developed services in rural areas” (author’s translation), facilitating various practical matters and decreasing vulnerability. Similarly, *employment in agriculture* could be an indicator that more people might be affected by climatic impacts and lose their jobs, or could be interpreted as indicating a well-developed agricultural sector, which in turn might be more resilient. A high population density or high unemployment rate could imply that many hands would be available to work in agriculture. Similarly, a participant referred to *employment in agriculture* as a “force in the sector” that would make it “less vulnerable” (authors’ translation), as it would indicate a strong agricultural region. A contradictory assessment was that the more people employed in agriculture in a region, or the higher the existing unemployment rate in a municipality, the higher the sensitivity to other negative impacts on this sector (or region), especially on farms that lack the option of an alternative income source.

#### 4.3. Missing indicators

Climate exposure indicators identified as missing concerned in particular extreme weather events, such as heavy precipitation or frost, but also climate variability – as one participant put it: “in particular, great variation is what impacts vulnerability a lot” (authors’ translation). Suggestions also focused on variables such as *rain intensity*, which was argued to be a more relevant indicator than *summer precipitation*, and more analytical/applied variables that could indicate the mapping of drought events, such as *how the groundwater content changes*. While there was agreement between participants that the indicator *autumn*

*temperature change* needs to be added, several discussions focused on the timing of various events, as the effects of certain changes vary greatly depending on the season and agricultural practice.

Another climatic variable discussed in one focus group session was wind, which was argued to be relevant to the efficiency of pesticide application, which might increase with warmer and wetter conditions. Participants further discussed how the variable *increased pests and weeds* could be included as an indicator, as it would exemplify an external pressure that affects agriculture. In this sense, participants discussed how different “impact” variables could be included in addition to the current exposure indicators, and as such “translate” exposure into more concrete terms.

A physical factor identified as a missing variable that would indicate the sensitivity or adaptive capacity of the agricultural sector was *sloped fields*, which would influence the need for drainage. The irregularity of field shapes was also mentioned in the discussion as an example of physical factors influencing vulnerability.

*Access to pesticides* was suggested as an adaptive capacity indicator, as were the *diversity of the farm enterprise* and *access to agricultural extension*. The latter would also function as an indicator of financial limitations, as being able to afford extension services was mentioned as an important factor affecting the ability to adapt.

In addition to the current sensitivity indicator *employment in agriculture*, information on *how people are employed* was said to be needed, for example, on whether farmers are working fulltime or seasonally, and on whether *economic support* is provided, including how EU subsidies are distributed. Furthermore, the *age structure* of people employed in agriculture was mentioned as a relevant sensitivity variable and indicator.

Additional factors considered particularly important, but equally hard to include as single indicators, concerned “politics” in general, including political decisions, practices, and messages and the need for political continuity, as well as decision makers’ knowledge and understanding of the challenges facing the agricultural sector. In particular, conflicts between environmental goals and agricultural development were cited by the participants as exemplifying experiences of politics and administration that counteracted good intentions:

Yes, but that’s what we scream about most – all of us, in every direction. A lot of good will is directed towards environmental improvement, but the wrong issues are addressed and the focus is on details, which tires people out and even often does not support, so to say, the genuine scientific basis. And I think that is a big, big dilemma. (authors’ translation)

Factors such as *rationalization*, *control measures*, and *incentive structures* along with *food contingency* were variables that could indicate political readiness to address future challenges and vulnerability in the agricultural sector. Similarly, other external pressures were listed, such as *food prices*, *imports*, *exports*, and the *world market* as well as *decreased focus on food in society*, which was mentioned as one reason for the decreased willingness to pay for agricultural food products. Similarly, other market indicators, such as *external prices*, *need to produce food*, and *profitability*, were listed as important variables that influence agricultural vulnerability. While many of these variables were considered exposure indicators, the general *lack of focus on agriculture in industrialized countries* was suggested as an indicator of decreased adaptive capacity.

Participants expressed general concern regarding policy and decision processes influencing the agricultural sector rather than climate change. Climate change was described as a minor challenge that is to some extent predictable and where adaptation can happen autonomously and successively, while the greatest challenge was described as the unpredictable changes in policy and decision processes. As one participant put it, “Climate change is somewhat predictable and possible to handle – it happens one step at a time – but this [i.e. politics/administration] is completely unpredictable” (authors’ translation).

## 5. Discussion

Regional quantitative assessments of agricultural vulnerability have been criticized for their limitations (Jones and Andrey, 2007; Hinkel, 2011). The present study revealed challenges similar to those identified in prior studies, in particular related to the spatial scale of data and selection of indicators (Birkmann, 2006; Vincent, 2007; Eriksen and Kelly, 2007; Asare-Kyei et al., 2015). The vulnerability index and sub-index scores constructed during focus group sessions might therefore not be highly conclusive. Nevertheless, the interactive vulnerability assessments resulted in extensive discussions of vulnerability indicators and of the factors underlying vulnerability. Moreover, the quantitative data on personalized settings complemented the qualitative data from the focus group discussions, strengthening the analysis.

One specific limitation discussed by the participants concerned the settings. While all participants were from the same geographic region, and were asked to pursue their assessment based on their experience in this region, the selection and weightings of indicators in AgroExplore were applied to the entire country. The participants did not consider this a fair basis for comparison, an argument also previously made by Adger et al. (2004), who advocated caution when applying uniform weightings of indicators across countries. In addition, regional differences became evident during focus group discussions. Participants cited examples of various factors that would be more relevant in other geographical areas than in the county of Östergötland. Furthermore, several participants were struggling with the concept of scale, as the data were presented as averages for each municipality. While this setting was selected to enable the comparison of administrative entities, and represented the lowest common denominator for many of the available datasets (cf. Wiréhn et al., 2017), the municipal level proved hard to relate to and several participants argued that many of the variables were unimportant at that level. Instead, there are significant differences between farms which would be more relevant to explore in a vulnerability assessment. Spatial scale in regional mapping is a recurring trade-off in terms of applying a higher aggregation level that allows for comparative analysis while simultaneously presenting high-resolution data with greater relevance to the user (Vincent, 2007; Wiréhn et al., 2017). This well-known limitation of maps of any kind also applies to geovisualization tools, as spatial information to be presented on a map is lost when generalized, for example, when higher-resolution data are aggregated to the municipal level.

While AgroExplore was designed to meet the demand for transparency in vulnerability assessments, participants still commented on a certain amount of experienced “black-boxing”. The fact that the users were able to select and weight the available indicators still did not enable them to see how much a selected indicator influenced a vulnerability dimension in “real” terms, as the data for each indicator are normalized to enable the calculation of composite indices. However, this is an inherent challenge in the application and presentation of indicator-based assessment, if the individual indicators are intended to be aggregated or comparable with one another (Tonmoy et al., 2014; Becker et al., 2015).

The results concerning participants’ perceptions of agricultural vulnerability to climate change in Sweden as well as the specific vulnerability indicators discussed during the sessions contributed to improved knowledge of the factors and processes that shape vulnerability. This is particularly important since European studies have historically had a general focus on *direct* climate change impacts, and not on the indirect effects and differential vulnerabilities (O’Brien et al., 2006).

The participants intensely discussed climate exposure indicators and perceived extreme weather events as more important than annual or seasonal mean changes, with the timing and intensity of events seen as particularly important. These results suggest a need to further investigate missing extreme weather variables and appropriate intensity and timing thresholds for constructing agriculturally relevant indicators of extreme weather events. Physical variables that were identified as

important for a comprehensive vulnerability assessment, such as the irregularity of field shapes, pose methodological challenges. Various metrics for shape complexity in agricultural landscapes (e.g. Moser et al., 2002) exist, and they may work as indicators of land use intensity since the rate of landscape transformation is suggested to be a function of land use intensity. Moreover, they could also work as species richness indicators, since land use intensification has been shown to have a negative effect on biodiversity (Moser et al., 2002).

Among the exposure indicators discussed during the focus group sessions, seasonal *spring* and *autumn precipitation change* were considered two of the most important and were weighted the highest. Summer precipitation change was not included as an indicator in AgroExplore, based on the reasoning that summer precipitation is not projected to change much and is therefore not a relevant exposure factor. The omission of this exposure indicator, however, made it problematic to draw conclusions regarding participant assessments of the relevance of spring and autumn precipitation in relation to summer precipitation. It has previously been argued that the understanding of the causes of vulnerability, needs to be enhanced in order to develop vulnerability indicators that can aid policy development (Eriksen and Kelly, 2007). This study’s visualization supported dialogues around commonly used generic indicators of agricultural vulnerability, increased the understanding of vulnerability and indicators of vulnerability for that specific system.

Furthermore, this study identifies a need to contextualize vulnerability indicators. Several participants remarked that they were uncertain which perspective they were applying when selecting and weighting indicators, as the related variables were assessed as having different influences depending on the farm type and crop. The participants had various perspectives on several indicators and made various assumptions regarding their correlations with vulnerability. The perspective on an indicator influences its assumed correlation with vulnerability as well as its classification as either a sensitivity or adaptive capacity indicator. For example, the discussion of *farm holding size* touched on both these aspects. A small farm could imply an enterprise supported by additional types of income and thus represent a way of spreading the risk; on the other hand, a larger farm has a higher investment capacity and therefore a higher ability to adapt. Summarized, the smaller the farm, the less sensitive it is, but the larger the farm, the higher its adaptive capacity – meaning that the perspective changes the assumed correlation with vulnerability as well as the vulnerability dimension. The analysis demonstrated that when indicators could be perceived from several perspectives, as demonstrated by the example of *farm holding size*, they were weighted low or deselected. Sensitivity indicators such as *clay content*, *phosphorus content*, and *pH* might have received low weights due to the potential lack of contextualization, but possibly also because such indicators were considered trivial when expressed as regional mean values.

These results relate to challenges addressed by, for example, Birkmann (2007) regarding how to contextualize indicators for sub-national and local levels, thus, how to adjust indicators to specific contexts and functions. This study emphasizes the importance of variable thresholds for indicating variables, which could be an important aspect in advancing the contextualization of indicators. In previous studies, a strain of discussion focused on indicator selection, the conflict between the desired explanatory power and data constraints, but not specifically on variable thresholds and how different thresholds have implications for what the indicator is perceived to represent. Several of the participatory dialogues in this study addressed the thresholds of various indicators. The notion of the magnitude and timing of rainfall is one case in which participants disagreed on the positive or negative correlations with vulnerability, and which raised the questions regarding the function of this particular indicator.

When identifying missing external factors, the participants pointed to a need to include measures to assess teleconnections (e.g. Benzie et al., 2016) influencing particular agricultural adaptive capacities. The

IPCC's Fifth Assessment Report stresses that "cross-regional phenomena can be crucial for understanding the ramifications of climate change at regional scales, and its impacts and policies of response" (Hewitson et al., 2014:1137). Still, climate change research on agriculture struggles to account for transnational climate impacts, that is, how global flows affect regional vulnerability and adaptive capacity. For example, how decreased or increased yields affect trade patterns, in turn influencing financial decisions, and how weather events may disrupt supply chains, induce migration, and intensify conflicts or cooperation, in turn affecting both food production and future demand.

In Sweden, the need to include transnational impacts in risk and vulnerability assessments has been highlighted in a report from the Swedish Meteorological and Hydrological Institute to the government (Andersson et al., 2015:133–144). How these transnational impacts can be systematically assessed remains a challenge, although several studies in recent years have set out to conceptually address the long-distance connections across borders and systems, and include teleconnections as well as telecoupled, indirect, secondary, and spillover effects (Adger et al., 2009; Liu et al., 2013; Schenker, 2013; Moser and Hart, 2015). Although these types of qualitative aspects are perceived important in representations of vulnerability, such characteristics are difficult to capture in indicators (Vincent, 2007), calling for other ways to include these in vulnerability assessments. The identification of relevant variable thresholds as well as the need for contextualization point towards the great challenge that remains in developing indicators that balance generic demands against being relevant and applicable in assessing agricultural vulnerability to climate change.

## 6. Conclusion

The results of this study contribute to the analysis of indicators that gauge vulnerability to climate change. Our results identify a number of critical challenges in the application of existing indicators and assessment methods to Nordic agricultural vulnerability to climate change. The inherent complexities, context dependencies, and multiple factors that need to be included in assessments entail difficulties in developing and identifying suitable indicators. Our analysis of how practitioners relate to and apply existing indicators to Nordic agriculture indicates a particular need for additional exposure factors to be incorporated in the assessments. These could, for example, be included as indicators of extreme events, such as days of heavy precipitation or without precipitation. Similarly, the combined effect of multiple climatic changes, such as low precipitation and high temperature, will require the development of more multi-factorial indicators. Several participants of the analysed focus groups pointed out that rather than climatic changes, it is policies and measures, primarily bureaucracy, are exposure factors that must be handled. O'Brien et al. (2006) and Kvalvik et al. (2011) similarly found that political regulations often were identified by stakeholders as a predominant adaptation challenge. Furthermore, external factors, such as global food demand, trade patterns, and climate change impact on agricultural production in other exporting countries, are increasingly influential teleconnections. For a robust assessment of vulnerability, these factors must be addressed by a broader set of both qualitative and quantitative indicators.

The results indicate that the commonly used indicators of climate change vulnerability in agriculture are too blunt and do not sufficiently capture the vulnerability contexts. In particular, threshold setting appeared to be an important factor affecting the relevance of indicators, as the discussions revealed that the specific threshold might influence whether an indicator (e.g. farm size) is considered to be correlated with increased or decreased vulnerability. Similarly, the distinction as to whether an indicator captures the sensitivity or adaptive capacity of a system requires further attention, as the practitioners involved in this study had different perspectives on the categories of single indicators and of the importance of this categorization. While this study supports Hinkel's (2011) finding that vulnerability indicators are not "fit for

[the] purpose" of supporting policy making, we argue that the crucial challenge of considering aspects of scale and context can be addressed by means of greater flexibility in assessment methodology. In particular, we identified a need for indicators and their thresholds being appropriated to context and scale of the specific issues assessed, to open up new perspectives on climate vulnerability in the agricultural sector.

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